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**Presidential Address.**

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SCIENCE AND THE MINERAL INDUSTRY.

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*Presidential Address by E. S. Simpson, D.Sc. (delivered on  
11th July, 1921).*

One of the most important lessons which the Great War has taught the peoples of the world is that self-preservation requires each nation in time of stress to be self-contained, not only in the matter of food supplies, but in supplies of all those various substances which form the basis of industries, particularly of key industries. Australia has for many generations been content to import from abroad, mainly by long sea routes, not only essential supplies which cannot be produced at all, or at any rate not readily on the spot, but also innumerable things which are found abundantly in her own domain, or could be manufactured from her own raw materials. We are led therefore to enquire is Australia securely self-contained in the matter of essential supplies, or is she condemned for ever to rely upon importation and storage against emergencies. This suggests the urgency of a scientific stock taking, in the greatest detail, of our natural resources and manufacturing capacity.

Let us take another standpoint. The last twelve months have witnessed a veritable collapse in all branches of our mineral industry with the exception of coal mining. The gold industry of this State in particular has dropped to about one-fourth of its magnitude of a few years ago, and the whole mineral industry in the State seems on the down grade, whilst all the largest base metal

mines in the Eastern States are closed down. Though this is due in part to new conditions which are outside the scope of the scientist, there are still many factors involved with which the scientist is alone equipped to deal. There certainly seems much that may be done to defer the closing of the fatal scissors formed of the converging lines of grade of ore and cost of treatment.

Taking as axioms that knowledge is power, and that ordered knowledge is the domain of the scientist, the two considerations that I have detailed offer abundant scope to the scientist in (Western) Australia, in the direction of sustaining and improving a flagging industry, whilst at the same time rendering our land during times of peace more secure in future times of stress.

The work that has been done during the present generation by our geologists in Australia is a monument to the value of geological science to all branches of the community. This work has received wide publicity and earned a large measure of popular recognition. For these reasons I do not intend to deal with it to-night, but shall confine myself rather to the position of the mineral and industrial chemist and physicist in relation to the mineral industry. In passing one might, however, be permitted to point out the great utility and urgency of an accurate definition by our geologists of the regional distribution of all the economic minerals.

Except indirectly through the engineer and metallurgist, the physicist has not come closely into contact with our mineral industry. For the metallurgical physicist there is still much to be done in the study of the effects of varying heat treatment upon the physical properties of simple metals and alloys, a thorough understanding of which would certainly tend to reduce the cost and widen the utilisation of these mineral products. For many generations there has been a widespread belief in the theory that ore deposits and underground water channels cause a local modification of the magnetic elements, a fact of the highest importance in prospecting if it should prove to be so. In the past the lack of detailed magnetic surveys has been a bar to any proper scientific investigation of this theory, and various charlatans and self-deluded persons have played on the credulity of the public and wasted capital and labour on the supposed evidence of various simple or complex instruments said to be capable of detecting ore, water, or petroleum at depths up to several thousands of feet. Now that the Carnegie Institute is well advanced with its magnetic survey and has chosen Western Australia as one of its first spheres of action, there is room for physicists to test this still doubtful theory, and to incidentally settle once for all, in a manner which will admit of no question, the value or otherwise of the many forms of mineral detectors, ranging from divining rods to complex instruments quoted at prices running into hundreds of pounds.

Of prime importance to this and every other country is the early compilation of a complete census of our mineral resources, whether the matter is viewed from the point of view of national safety, or of facility of mineral production or of economy of manufacture. The foundations of this have been laid by our Geological Survey during the past 25 years. It is only, however, the foundations that have been laid, and the completion of the stocktaking will tax for many years to come the energies of all our available geologists, chemists, physicists and quantity surveyors. Such a stocktaking can never be finalised as new discoveries are made from year to year, but only when it is completed right up to date will we be in a position to meet all national emergencies, and to manufacture essential mineral products in successful competition with foreign rivals.

Questions of organisation and administration are not usually looked upon amongst us as lying within the ambit of the scientist, though rightly I think, so considered by our cousins of the United States. The present organisation of our mine staffs certainly deserves careful thought. The prime objects of a mining engineer are to detect and follow ore bodies and to exploit and bring the ore to the surface. It is for these duties that he receives a long and careful education, and if through any cause he is compelled to neglect these duties, they are imperfectly and uneconomically carried out by someone less efficient in this particular direction. Too often these days a mine manager's time and thought are expended on labour troubles, or preparing evidence and attending arbitration courts. This is surely not as it should be, for under these conditions the mining engineers' special technical knowledge is being lost to the mine he controls, with a disastrous effect upon the life and economic productiveness of the property. The possibility of groups of mines employing collectively labour and arbitration experts, leaving their engineering staffs free to concentrate their energies on engineering problems, seems worthy of consideration as one method of dealing with the existing unsatisfactory condition of affairs.

Let us consider some aspects of the relationship of the chemist to the mineral industry. One should bear in mind from the outset that Nature herself is the super chemist, with her mighty workshops and ceaseless activity through countless ages. Very little consideration will lead us to realise that all man's activities are ultimately dependent upon the continued supply by nature at the earth's surface of crude mineral matter of suitable kind for the use of living organisms. To-night we are specially concerned with the necessary supply to mankind of the minerals, metals and inorganic salts, which form the basis of the mineral industry, and which in times of peace our modern civilisation is demanding yearly at a rapidly increasing rate, and which in times of war are essential to our national defence.



The ultimate source of all our supplies of the valuable metals is the magma or molten rock of the primeval surface of the globe. No one has positively identified any mass of this magma in either still fluid or congealed form, but a study of the visible products of its alteration enables us to arrive at a very fair estimate, though admittedly not a rigid one, of the quantities of those valuable constituents which were presumably more or less homogeneously distributed through the primeval magma. On the basis of the numerous rock analyses which have been made all over the world, and upon calculations of the relative quantities of the different rocks disclosed at and near the surface, estimates have been made from time to time of the average quantities of the various elements distributed through that comparatively thin crustal portion of the globe, the so-called "lithosphere," which is within reach of living organisms and man in particular. These estimates are rather startling at first sight, since they show that out of 83 known elements the majority of which has become indispensable to us, two, viz., oxygen and silicon, together monopolise 75 per cent. of the whole earth's crust. Only six others are present to the extent of between one and ten per cent., viz., aluminium, iron, calcium, magnesium, sodium and potassium; and three others, titanium, phosphorus and hydrogen are present to the extent exceeding one part in one thousand. Of the remaining 72 elements, several like carbon absolutely essential to life, 11 are present in quantities less than one part in one thousand, whilst others equally essential to our present day machine-made civilisation, such as copper, the other heavy metals, iodine or arsenic, were distributed on the whole through the crustal magma only in minute proportions amounting to less than one part in ten thousand, or in such a proportion as would utterly prohibit our collection of them in suitable quantities to supply our present day necessities, were they to have remained thus evenly distributed.

Fortunately for us nature is above all the great concentrator of her own widely dispersed wealth, this concentration being dependent to some extent upon purely physical and mechanical processes, but in the main upon chemical processes which it behoves the chemist of the present day to study closely, lest mankind, having rifled to exhaustion the more obvious and easily accessible of nature's storehouses, shall find itself without the knowledge which will enable it to maintain its sources of essential supplies.

Geochemistry, the chemistry of the earth's crust, is not by any means a new science, though its name is somewhat new, but it is a science which has been greatly neglected in most civilised countries. The birth of geochemistry was in fact coincident with the birth of the sciences of chemistry and mineralogy, since amongst the first substances to be subjected to chemical analysis were some of the commoner minerals, and in still earlier times manufactures

had been built up which depended upon the accidentally discovered, unsystematised and limited knowledge of the chemistry of certain mineral compounds.

It is unfortunately, however, a fact that in spite of the importance of the mineral industry and the large number of people employed in it, the science of geochemistry has not advanced to anything like the extent that its sister sciences have done. Mineralogists have concentrated their attention too greatly upon physical characters, which are rarely of importance in the practical utilisation of minerals. The chemical properties of minerals have been the subject of comparatively little research, such work as has been done in this field being for the most part the mere piling up of innumerable analyses of simple minerals, and of those common mineral aggregates which we know as rocks and metallic ores. It is only in recent years and in a minority of cases that these analyses have been done with that completeness and exactitude which modern theoretical science demands as the basis of its generalisations, and modern industry demands as a basis of its processes. Now whilst it is very necessary to make and record mineral analyses and rock analyses, particularly from new regions, these are after all only the rough unshapen stones of which the edifice of this science is to be built. If the science is to be of any direct benefit to mankind, as it can and must be in ways which I hope in some measure to indicate to you, something very much more is required of its devotees than the mere multiplication of rock and mineral analyses.

The subject of mineral genesis including the origin of ore deposits in which term are included those natural concentrations of all minerals of economic value to civilised man—requires the closest attention of the scientific world at the present juncture. These problems involve the application of certain physical and mechanical principles, but are essentially chemical ones, and ones the solution of which are likely to lead to the most valuable economic application, besides enlarging the boundaries of our knowledge of pure science. The discovery of the exact cause of a disease is a big step in the direction of combating it, and similarly the discovery of the exact source and mode of formation of a mineral must prove a big step in the direction of finding and following workable deposits of it. This is one way in which the study of geochemistry should yield a rich reward to the successful investigator, and galvanise the mineral industry into fresh vigour.

What are the origins of the many, but by no means innumerable, storehouses of nature's chemical concentrates? When we have exhausted the more obvious of these, where are we to search for others that our civilisation may not be brought to a standstill? The answers to these two questions will be found in the main by the application of chemical principles. In the earliest days of his

existence upon the earth man only benefited by those elements which were widely and more or less evenly distributed throughout the earth's immediate surface, or was led by blind chance to concentrations of those others which his growing knowledge led him to look upon as indispensable. As time went on an exhaustion of some of the widely distributed elements was already apparent, the local exhaustion of phosphorus in the soil for instance, and man became more than ever dependent upon natural concentrations and upon his purely chance discovery of them. First to his aid came a glimmering of the relationship between ore deposits and physiographical and geostructural features. Last, and to an imperfect extent, geochemical principles are being, and must continue to be, developed to guide him in his search. Some few broad geochemical ideas are of common knowledge, and often unconsciously applied. Such for example as that chromite (chrome ore) is invariably associated with rocks of a definite chemical type, viz., the so-called ultra-basic rocks: that galena and silver minerals are almost always found together in genetic relationship: that pyrites and gold are not uncommonly co-precipitated in nature: that commercial felspar is never found anywhere but in the products of consolidation of acid, *i.e.*, peralitic magmas. A few such truths are widely known and freely made use of in practical mining, but little appreciation is yet shown of the fact that other similar genetic relations of a chemical nature are fairly well established and many others must be awaiting discovery, with equal possibilities of practical application in the two branches of mining, viz., prospecting, or the detection of new masses of ore, and exploitation, or the following up and bringing to the surface of the whole valuable portion of a known mass.

Your attention has already been drawn to the fact that in Western Australia mining has reached a stage of serious decline, which has already reacted deleteriously upon the whole community and can only be remedied in one of two ways, viz., by the early discovery of new mineral deposits equally profitable to those which have been worked in the past, or by the reduction of the cost of working those known deposits to such an extent as to widen considerably the limits of payable ore. Science can render aid in both directions.

Sir William Crooks, in his Presidential Address to the British Association in 1898, was the first to sound the ominous note of Famine in regard to mineral supplies necessary for our existence. In this notable address he pointed out the absolute dependence of man on a sufficiency of nitrogenous food, and the impossibility of producing this without an unfailing and indeed increasing supply of soluble nitrates or ammonia salts. At the same time statistics proved that our then known natural sources of both, viz., the mineral nitrates of Chili and India, and the coals of known and strictly



limited coal fields, were diminishing at a rapid rate. In this case the chemist, physicist and engineer have already come to the rescue of mankind, and the economic conversion into fertilising salts on a large scale of the unlimited and ever renewed supply of atmospheric nitrogen is a tangible proof of the success of their endeavours.

The nitrogen famine is a bogey of the past, but local Australian famines, *e.g.*, in potash, mercury and platinum are only too apparent in times of emergency, and a shortage of gold is not by any means unlikely in the near future. We have therefore reached a stage in the world's history when the geochemist and geophysicist are increasingly important members of the community.

Our gold yield is steadily decreasing and with it one of our greatest sources of wealth. Every month we hear of mines being closed down because the working expenses, and value of ore in sight, factors which have been steadily converging during recent years, have at last reached the same level and passed beyond it. Can the scientist be of any service in remedying this? I unhesitatingly answer, yes. One direction in which the chemist can help I shall deal with more fully later, *viz.*, in devising cheaper methods of extraction, using chemical processes and reagents less expensive than those now used. I wish to consider an entirely different line of assistance, one that has been less studied by chemists, and one therefore which offers more scope and greater chances of obtaining successful results. I refer to the assistance which can be given to prospecting, using the term to cover not only the detection of quite new concentrations of gold, but the tracing of the entire course of those already disclosed. At present through a grievous lack of scientific knowledge, both phases are largely directed by the ruinously expensive process of "blind stabbing," the chance opening of prospecting shafts, drives and bores, guided only by imperfectly understood laws of geological structure and mechanical fissuring. Although these factors have considerable influence on the position and form of ore-deposits, the preponderating influence is chemical, being a matter of solubilities, ionisation, hydrolysis, oxidation, reduction, double decomposition, mass action and reversibility of reactions under variations of temperature and pressure.

To the majority of persons actively engaged in our primary mineral industries many of these terms are meaningless. It is doubtful if any of them could apply them at present with any practical effect to the problem of reducing the cost of searching for continued supplies of payable ore. For this the chemist himself is mainly to blame, for except in the domain of secondary enrichment, chemical investigation in the field of ore deposits has been comparatively meagre and unsystematic.

It should not therefore be labour lost to bring before the scientists of this State, which has owed so much in the past to a

now languishing gold industry, an outline of the main principles concerned in the formation of ore deposits, particularly of gold deposits.

I have already indicated to you the widely scattered nature of our original elemental supplies and their low concentration, with very few exceptions, in the great mass of the earth's crust. What are the nature and origin of the concentrations upon which we must depend for our industrial supplies? Of the three components of the outer accessible portion of the earth, the atmosphere will yield us only oxygen, nitrogen and water amongst all the many elements and simple compounds we require. The second great crustal division, the ocean and lakes, or hydrosphere, now yield and will continue to yield us, in addition to water, sodium and chlorine, and possibly in the future potassium, which it contains to the extent of four parts in ten thousand. It is evident that it is on the lithosphere, or solid crust of the earth, that the chemist is, and will be, dependent for most of his material, whether he is engaged upon purely scientific investigations or on industrial manufacture. To appreciate the facts and problems of ore deposition some knowledge of the earth's crust is essential.

The modern geologist has used a chemical basis for his division of the lithosphere into several concentric zones and belts. The upper zone or zone of katanorphism, is characterised by exothermal reactions and by the preponderating formation of simple compounds from more complex ones. It is divided into two "belts," the upper "belt of weathering" in which aqueous solution, oxidation and carbonation are the most prominent features: the lower "belt of cementation" in which hydration of pre-existing compounds and filling of spaces by deposition from solution are predominant.

At a depth of approximately 10,000 metres begins the second great zone of the lithosphere, the "zone of anamorphism," characterised by the predominance of endothermal reactions, particularly silication and dehydration, and by the building up of complex molecules from simpler ones. Under the enormous pressure existing at this depth all known mineral masses are plastic, and therefore cavities, other than subcapillary ones, must be absent.

Beneath the zone of anamorphism and at times bursting through both this and the overlying zones, is the zone of actual or potential fluidity, actual probably only under local conditions of reduced pressure.

Beneath this again is the "barysphere." The average density of the whole earth as determined by astronomical methods is 5.6, whilst the average density of the lithosphere, *i.e.*, the top 10 miles of the solid crust, is given by competent authorities at 2.7. We must therefore assume that below the lithosphere there is a barysphere, *i.e.*, a mass of minerals with high specific gravity. The



only minerals we can conceive of this nature are those containing a large proportion of the heavy metals, such mineral in fact as would, when found within reach of man, be considered as metallic ores.

Having thus briefly considered the various zones of the upper portions of the earth we are in a position to consider the theory of origin of the more important of those primary subsurface concentrations of metallic ores which we call ore deposits, and which supply us with all our heavy metals, particularly, so far as we are concerned, with gold.

In the 80's and 90's of the last century two rival schools of thought as to the origin of these metalliferous ores waged a wordy warfare. The rival theories were those of "lateral secretion" and "ascension." The supporters of the former theory urged that these metallic ore deposits were precipitates in fissures or other cavities from solutions which seeped laterally into them from the walls immediately adjacent. That these solutions were aqueous solutions of metals derived from the widely distributed but minute amount of metals occurring in the surrounding rocks flanking the deposit. The bases of this theory were the known and assumed movements of water underground and the many determinations by Forshammer and Sandberger of the presence of traces of heavy metals in the rocks, and rock forming minerals of mining districts. Apart from the fact that it is just as probable that such traces may have been distributed from the vein into the surrounding rocks, as that the reverse movement took place, there is considerable doubt attaching to several of these determinations, particularly with regard to the methods used for the estimation of minute amounts of gold, silver, and zinc, many of the determinations of these being now looked upon with grave suspicion.

The supporters of the now generally accepted theory of "ascension" consider that all the valuable constituents of primary ore deposits were brought into their present position in solution or as vapours from considerable depths within the zone of fluidity or the underlying barysphere. Ore deposits are notoriously associated with intrusive rocks, which are known to carry much water and small amounts of heavy metals. During the consolidation of such rocks from fluidity, a chemical process goes on akin to that which takes place in the concentration of sea water. Large amounts of the most abundant components first crystallise out, leaving towards the end of the process a "brine" in which are concentrated the valuable metallic constituents in the form of soluble salts and ions in solution in the residual water, which finds its way into adjacent and overlying fissures and cavities and often by energetic chemical action dissolves spaces in surrounding rocks and precipitates in these spaces new minerals partly of economic value.

The composition of these original metalliferous solutions and the precipitation of the metals from them during their migration, by changes in temperature and pressure, by interaction with other solutions derived from elsewhere, or by interaction with the solid minerals with which they come in contact, all these are matters demanding the closest study. Only when they are thoroughly investigated and understood will the present unscientific and wasteful methods of prospecting and development give place to thoroughly scientific and therefore economical methods.

One of the earliest theories of the origin of gold deposits, and one which still prevails almost universally is that the gold was originally a very minor constituent of a molten magma, the solidification of which resulted in a concentration of practically the whole of the metal in the form of gold chloride in a comparatively small volume of water. This solution rising under pressure into cavities in the zone of anamorphism and katamorphism met there with reducing agents, particularly with the carbon of fossil vegetable matter, which produced a separation of the metal. If this be so the richer portion of the gold deposit should be found adjacent to carbonaceous portions of the wall rocks, and the worthless portions of a gold deposit adjacent to those portions lacking in carbon. This theory appears to be borne out by facts in some few cases, *e.g.*, at Bendigo, and has resulted in a scientific direction of prospecting operations in certain districts.

The study, however, of the majority of Western Australian gold deposits, and of many in other parts of the world, shows this theory to be completely inapplicable in the majority of cases. In a description of the Kalgoorlie deposits published in 1912, I first promulgated the theory that the gold in the primary solutions of magmatic origin was present not in the form of chloride but in the form of the sulphaurate anion,  $(AuS_2)$ . Simultaneously and independently a similar suggestion was put forward by Professor Lenher of California to explain the primary introduction of gold into some of the rich veins of that State. The main facts upon which this theory was based by myself are briefly:—

1. The invariable association of free gold and pyrite and the very frequent quantitative substitution of the latter for previously existing iron silicates :
2. The association at Kalgoorlie, Ora Banda and elsewhere of free gold with tellurides of gold, silver, and other metals soluble as sulphosalts :
3. The frequent absence of any concentration of gold in the immediate neighbourhood of bands of graphitic material, whilst the contrary would be the case if gold had arrived in the form of solutions of auric chloride and auric cation :

4. The frequent presence of secondary potash minerals, chiefly muscovite, in auriferous metasomatic lodes, this potash being largely in excess of that in the original rock :
5. The frequent enrichment of gold veins, *e.g.*, at Lennonville, at the intersections with previously existing bands of haematite (ferric oxide), a moderately strong oxidising agent :
6. The occasional intimate association of gold with other strongly oxidising agents, for example, with manganese dioxide at Kanowna, and with chromium compounds at Westonia.

These six conditions associated with enhanced gold precipitation do not appear to be compatible with the theory of the introduction of gold in the form of solutions of auric chloride and auric cation, whilst they are intelligible with the theory of the introduction of gold in magmatic waters carrying potassium sulphate and free sulphate anion.

The purely chemical aspect of the genesis of gold in our primary gold deposits is one which is in urgent need of investigation, and I think you will agree with me that the solution of this problem cannot but have a very important bearing upon the prospecting and exploiting of such deposits both in Western Australia and elsewhere.

In quite a different direction altogether the mineral chemist is destined to play a large part in the near future. Up till now, thanks to nature's industry, we have been enabled to obtain sufficiently large supplies for our necessities of such minerals as are usually adapted to manufacturing processes. In consequence, a very superficial and incomplete knowledge of the chemistry of minerals has enabled us to keep the world supplied with all its needs of soluble potash and phosphorus salts, of metallic aluminium, copper and iron, and so on. The war has already proved to us the grave danger of relying too completely upon a single source of any essential mineral product, and the rapid exhaustion of high grade crude minerals all the world over will compel us to a closer chemical study of the lower grade minerals upon which we are destined to become more and more dependent.

As an example of what scientific assistance can be given in this direction let us consider the position in relation to potash supplies created by the war. The Germans have been favoured by Nature with an immense supply of high grade and easily treated potash minerals. Because of this they had by 1914 monopolised the whole potash supply of the world. The cutting off of this supply created a potash famine in Australia, affecting many industries but particularly fruit and potato growing. To relieve



the situation two courses were open to us, either to discover in Australia a supply of easily utilised salts of the German type or to locate other potash minerals and devise means for their economic utilisation.

To the monumental work of several scientists, particularly J. Usiglio, C. Oehsenins and J. H. Van't Hoff, is due the thorough understanding of the origin of the famous German potash deposits through the evaporation under normal conditions of temperature and pressure of a completely or almost completely land locked mass of ocean water. The complete details of the whole process have been so thoroughly investigated that the exact order of deposition of the various simple and complex salts of sodium potassium, magnesium and calcium, and their conditions of stability are so well known that should a similar basin be met with elsewhere, the prospecting of it could be carried out in the most scientific and least expensive fashion. Although the conditions favourable to the concentration of these minerals in commercial quantities are known to exist in several localities at the present day, *e.g.*, in the Dead Sea, the Caspian Sea, etc., and although similar conditions must have frequently prevailed in past geological ages, the chances of finding other workable deposits of this kind appear every year to be more remote, the ready solubility in water of the valuable minerals rendering them too liable to be dispersed again in succeeding ages and returned to the ocean, or by interaction with kaolin and halloysite converted into insoluble and valueless mica. Certain it is that in Australia no discovery of such beds was made, and supplies of potash to meet this and other emergencies had to be sought elsewhere. This search was eminently successful.

At that time only two other minerals were receiving serious attention as possible sources of potash, viz., feldspar and alunite. Potassium is estimated to form 2.46 per cent.\* of the whole lithosphere, and the average potassium in the earth's crust within the Australian Continent is beyond doubt very close to the average for the whole earth, so that a surface slice of Australia 10 feet deep contains about  $1\frac{1}{2}$  billion tons of potassium or, on the average, half-a-million tons to the square mile. It seems almost incredible at first sight therefore that we should ever be faced in Australia with a potash famine. The difficulties of course are that this potash is irregularly distributed and even where plentiful is almost wholly present as feldspar or mica and thus not readily available as plant food either in its widely distributed form or in its known concentrations. It should be borne in mind, however, that the Darling Ranges within a few miles of Perth are composed of granite with an average content of five per cent. of potash, *i.e.*, two cwt. of potash in every cubic yard, or one million tons of potash per square mile 10 feet thick. Not only is there this huge amount of

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\* F. W. Clarke, data of Geochemistry, 4th edition (1920).

five per cent. potash ore at our very doors, but in the same ranges are numerous concentrations in the shape of pegmatite veins in which the potash is estimated to rise to 7 or 8 per cent., and these by hand picking would yield raw material with at least 10 per cent. potash. It would be a worthy and profitable research to work out in the most complete detail all the chemical properties of this felspar (microcline) which in its natural state contains no less than 12 to 13 per cent. of potash,\* with a view of making its potash available industrially. In some parts of the world this has been done on a small scale in connection with the cement industry by acting on the felspar and associated mica at a high temperature with lime and a little salt and thus volatilising the potash and collecting it as flue dust. As a bye-product in cement making, however, the output is limited by the output of cement, being something like two per cent. only of the latter, an amount entirely inadequate to supply the demand. The same remarks also apply to the English attempts at recovering potash from iron blast furnaces. Other methods of utilisation have therefore to be sought.

At the local pre-war rate for potash every ton of Darling Range granite contained 32/6 worth of this indispensable material, a value almost doubled at the present time, and likely to be enhanced for many years to come. At present rates the average pegmatite veins carry 77/- to 88/- worth of potash per ton, and felspar concentrates could readily be obtained from them by hand picking which would carry £5 worth per ton. It seems as if the value of the contents is not so low as to put out of count the possibility of making the treatment of such material a commercial success, and there is every possibility of a big reward awaiting the scientist who successfully solves the problem of extracting commercial salts from such felspathic ore. Metallurgists in the past have succeeded in overcoming obstacles just as great and even greater.

The principal other mineral which had been considered as a source of potash was one of a very different type and origin, viz., alunite, a basic sulphate of aluminium and potassium. Up till 1917 this mineral had only been utilised for the production of alum and very few workable deposits of it were known in the world, one of them being in New South Wales, but none at all in Western Australia. The origin of the mineral was obscure and therefore there was no scientific basis upon which to prospect for supplies of the mineral.

One of the first steps towards solving the problem of potash supplies was plainly to determine the mode of origin of alunite. A close study of all the known occurrences of the mineral led to the conclusion that it owed its origin to the oxidation of pyrites in the presence of potash mica or felspar. Plainly, therefore, alunite was

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\* By analysis of local felspars. See E.S.S. Sources of industrial potash in Western Australia. G.S.W.A., Bull. 77. Perth, 1919.

to be sought in areas of pyritous shales or in metalliferous districts, particularly in those parts of them where pyrites was largely developed. Following this argument, and favoured by fortune, deposits of alunite were in a short time located at Kanowna, Wallangie, Northampton and Ravensthorpe. Of these localities Kanowna soon proved itself capable of yielding large commercial supplies at a reasonable cost. At about the same time alunite was found for the first time in South Australia, at Carrickalinga and Warnertown. The first part of the problem was thus solved.

There remained to be worked out methods of treatment which would yield, 1st, a water soluble but possibly impure material suitable for agricultural purposes: 2nd, a pure or almost pure salt suitable for industrial or therapeutical use. Both have been accomplished, though the task was rendered difficult by the fact that very little was known about the chemistry of alunite, and what little had been published had been proved to be faulty. The details of the investigations have been laid before you during the year. The results obtained were briefly, that (1.) a suitable water soluble fertiliser was obtained from the mineral either by roasting or by mixing the raw mineral with a suitable amount of caustic or slaked lime: (2) a salt suitable for industrial purposes was obtained by roasting and extracting with hot water, and then crystallising.

The iron compound homologous to alunite is jarosite, a mineral considered up till quite recently to be of rare occurrence, and nowhere previously known to occur in sufficient quantities to be of commercial importance. The only known Australian locality was Coglin, in South Australia. It was obvious, however, that if a sufficiently large deposit of the mineral could be located, and if its chemical properties should resemble those of alunite, a second source of industrial potash would be available. Diligent search has led to the detection of this mineral in Western Australia at Nullagine, Whim Creek, Northampton, Love's Find, Upper Kalgan River and Ravensthorpe. At several of these localities, particularly the last, there appear to be commercial quantities. Quite recently following the publicity given to jarosite in this State, large deposits of the mineral have been shown to occur near Anglesea in Victoria.

Nothing was previously known of the chemistry of jarosite but researches now well advanced have proved that (1) a suitable water soluble fertiliser is obtainable by roasting the mineral, or by mixing it with a suitable proportion of lime, or by extracting it with lime water: (2) a salt suitable for industrial purposes is obtainable by roasting, extracting with hot water and crystallising.

The work already done on alunite and jarosite make it certain that in any serious emergency Australia can supply itself with potash.



Another potassium mineral which has received consideration is Glaucconite, a hydrous silicate of potash and iron. Originally formed by precipitation in the beds of oceans, it is brought within reach of mankind by the secular upheaval of these beds into dry land. This mineral suggests itself as a possible source of commercial potash by its wide distribution in large quantities in the so-called "greensands" of many parts of the world, including our own State. In the Cretaceous rocks extending from Cingin northwards are considerable thicknesses of unconsolidated greensand consisting of a mixture of loose granules of quartz and glaucconite. The latter mineral averages between seven and eight per cent. of potash and three facts make it attractive as a source of potash: Firstly, the loose nature of the mixture, which points to a mechanical concentration being cheaply and easily feasible: Secondly, the complete chemical inertness of the principal gangue, quartz: Thirdly, the chemical instability of the glaucconite itself, which leaves it open to attack by many comparatively weak chemical agents. Here is a field for research distinctly inviting to West Australian chemists.

Beyond these two minerals the only other common mineral which suggests itself as a source of potash is Muscovite, the potash mica. Here again we have a mineral carrying from seven to 10 per cent. of potash but very stable and inactive, and presenting most, if not all of the difficulties of treatment of Felspar, whilst at the same time less frequently concentrated than the latter. It is quite possible, however, that the extraction of potash from mica may be simpler than from felspar, and if it should prove to be so, considerable quantities of mineral would be available for treatment, particularly if it could be treated in conjunction with felspar.

To complete the survey of the possible sources of potash in the lithosphere it was necessary to consider quite another problem altogether. This is the atmospheric weathering of rocks and the connection between this process and the nature and quantity of the dissolved salts in underground waters and, ultimately, in the waters of the ocean. I have already drawn your attention to the fact that the Darling Range granite carries in its unweathered state one million tons of potash in every square mile 10 feet deep. In addition, it carries about three-fifths million tons of soda. Now if one pays a visit to any clay or gravel pit in these ranges one finds that the granite is completely weathered over large areas to a depth of at least 10 feet, often much deeper, and that the residual material carries only traces of alkalis. A study of the processes of weathering leads one to the conclusions (1) that all these alkalis have been dissolved in surface and subsurface waters: (2) that they have not been reprecipitated in the immediate vicinity. What has become of all this dissolved potash and soda? The soda I think can be quite satisfactorily accounted for by the soda of the ocean,

river, and underground waters, but not so the potash. In the average of all these waters the ratio of potash to soda is only something like 1 to 30, whilst in the lithosphere as a whole, the soda only exceeds the potash in the proportion of 11 to 10. A prolonged and careful investigation of this problem has led to the conclusion that the greater part of the naturally dissolved potash slowly recombines with the kaolin and halloysite of sedimentary beds forming sericite. In the newer shales there is but little sericite and chlorite and much kaolin and halloysite; in the older ones more sericite and chlorite and correspondingly less kaolin and halloysite; in the oldest ones there is neither kaolin nor halloysite, their place being taken by sericite, and to a less extent by chlorite. It appears from this investigation that the essential difference between shale and slate is not one of physical structure but the far more fundamental one of chemical and mineral composition. A slate is in fact to be defined as a shale altered by the complete or almost complete conversion of original kaolin and halloysite into sericite and chlorite. The practical application of these results to the problem of potash supply lies in the knowledge obtained that the greater part of the potash dissolved during rock weathering is permanently lost to mankind, as it would be hopeless to attempt to extract it from slates. The balance of this potash is to be sought in deposits of glauconite, alunite, jarosite, and a few lesser known minerals, many of which are undoubtedly more abundant than has hitherto been supposed.

The discussion of the utilisation of other sources of potash than those of the German mineral salts upon which we have become so dependent, raises the general question of what may be called the metallurgical interest of the chemist in Nature's chemicals, that is to say, the interest which should be taken in the study of the chemistry of the minerals of the earth's crust with a view to converting them more readily and more economically into the commercial products necessary for our every day life. One might be tempted to say at first sight that the cyanide process has led to such a convenient and cheap means of extracting gold from its ores, that here at least there is no room for experimentation. Yet we know that gold millers raise increasing complaints regarding the cost of treatment, and so long as cyanide remains a comparatively high priced chemical, and so long as no solution to the problem of preventing the large destruction of cyanide by such common associates of gold as arsenopyrite, iron sulphates and copper carbonates, there is ample room for the mineral chemist to work a revolution in the wet extraction of gold.

At a later stage I shall refer somewhat more fully to the sources of our natural supplies of phosphorus. The metallurgical aspect appeals to us in the case of this substance. A somewhat recent paper\* on the phosphates of Florida read before the American

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\*J. A. Baw: "Use of Low Grade Phosphates."

Institute of Mining Engineers, makes the astounding acknowledgment that only 25 per cent. of the phosphorus in the crude rock which is worked is actually recovered, 75 per cent. being lost in the tailings. Here is food for thought for anyone interested in problems of economy of natural resources. In our own case, so long as we have a plentiful supply of high-grade phosphate rock coming to us from over the seas we remain in the same calm state of contentment as we did in regard to our potash supplies, and make little or no effort to utilise local lower grade or less soluble minerals. It is quite possible, however, that through some cause or another our overseas supplies may one day be stopped or at least reduced to less than our reasonable requirements, and it would not be out of place therefore for our scientists to interest themselves in our Australian phosphatic minerals and make a complete study of the chemistry of these substances with a view to their economic utilisation.

Other similar cases will suggest themselves on a little mature consideration. For example, how was it that although before the war the British Empire produced about three-quarters of the tungsten ores of the world, and utilised more than one-half of the pure tungsten compounds prepared from them, the metallurgy of the metal was left wholly in the hands of the Germans, with very serious results from a munition point of view in the early days of the war.

It is astonishing to note to what an extent in the past the chemical side of the science of Mineralogy has been absolutely neglected and the physical side, particularly the crystallographic and optical, developed to extremes. As a matter of fact the utilisation of minerals in the service of mankind depends, in nine cases out of ten, on their chemical properties and not on their physical. Just consider for a moment how few minerals are used like diamonds or quartz for their optical properties, or asbestos for its infusibility, or mica for its resistance to the passage of the electric current. And on the contrary, how very many economic minerals depend entirely for their value upon their chemical properties, for example, pyrite, or apatite, or calcite, or salt. There is undoubtedly a crying need for a much fuller treatment of the chemical properties of minerals in our text books and courses of study. Who can doubt which is the more important piece of knowledge to impart to a student of mineralogy, that haematite crystallises in the hexagonal system, or that haematite is reduced to metallic iron when heated to a high temperature with carbon.

A new branch of geochemistry which promises to yield many results of great practical importance has recently been brought into prominence through the researches and publications of a Russian professor of Mineralogy, J. V. Samoilow of Moscow. This science though essentially chemical and mineralogical in its scope,



has been given by Samoilow, the most misleading name of Paleophysiology, a name which I trust will soon pass out of use in favour of one more truly significant. The science deals with the origin and development of those minerals in whose history animal or vegetable organisms have played an important part as primary or later concentrating agents. Its practical application is likely to lie in the assistance it will render in the search for new deposits of certain economic minerals, such for example as apatite and celestite (strontium sulphate), and in the economical exploitation of such deposits, since it will soon be possible in the light of the new facts of this science for the prospector and miner in such instances to profit to a very considerably greater degree than heretofore from the historical, palaeontological and structural data collected by the field geologist.

The foundations of this branch of science were laid many years ago, when the relationship was first established between economically important beds of limestone and the powers possessed by corals, echinoids and other marine organisms of extracting from sea water and secreting again in their skeletal systems the carbonate of lime present in such a diluted form in the waters of the ocean. But for the primary concentrating power of such organisms our supplies of lime compounds of all kinds would be infinitely more difficult to obtain than they are at present. With the present abundance of calcite of sufficient purity for most of our demands there is, however, no urgent call for the scientific investigation of the many organic sources of calcite and aragonite and of the history of their development into commercial deposits.

Another section of this science to which in the past a good deal of attention has been paid is the origin and history of our available phosphate deposits. Here we are, however, immediately on a different footing to what we were in the case of calcite, whether from a standpoint of scientific interest, of economic importance, of complexity and multiplicity of the chemical changes involved and final products resulting, or of discontinuity in the data available. No exposition of the facts of this series of chemical reactions approaching anything like completeness has ever been published, nor will be for many years to come. Yet consider one small practical application of such a complete mass of data accompanied by reasoned deductions and generalisations. In Western Australia we are in constant need of a cheap supply of phosphates suitable for agricultural purposes. To the north of Perth is an immense area of rocks which at several points exhibit outcrops of natural phosphates either slightly too poor or too insoluble to use under present conditions. The stratigraphy of the region is not obscure, but without the necessary knowledge of the past methods of formation and accumulation of the phosphate minerals, we are at an absolute loss where to look within this region for higher grade and

more soluble crude material. in fact we are not in a position to decide whether there is any hope at all of finding such more valuable ore.

A brief resumé of the accepted theory of phosphorus concentration may serve to draw attention to the many weak points in our chain of knowledge which requires further investigation. The origin of all the phosphorus now available to man is the phosphorus of the primeval surface magma, which has crystallised out in the present lithosphere almost entirely as apatite, the fluophosphate of calcium. The average phosphorus content of the lithosphere is 0.28 per cent. of  $P_2O_5$ . A large decrease in concentration takes place when this apatite passes into solution in the soil waters, and thence into vegetable organisms. From the latter a small proportion of the total phosphorus passes into land animals where large concentration occurs, placing within reach of man for his use an appreciable tonnage of "bone phosphate." By far the greater part of the phosphate dissolved from weathering rock passes however into the ocean in an extreme state of dilution, where it is first absorbed by marine flora, subsequently by the intervention of fish, arthropods and mollusca, and in past ages by marine reptiles, reaching an appreciable concentration in the bony framework of such creatures. Fish bones as such, are not used to any great extent as a phosphatic manure, but the ingestion of bony fish by other carnivorous fish as well as by reptiles and birds, all of which excrete the greater part of the phosphatic material in a new and more soluble form, has led to the chief concentration upon which man depends for his supplies of agricultural phosphorus. The guano deposits and associated rock phosphates are fairly well known, though the total number and chemical nature of the various minerals occurring in them is not yet known with any certainty. The story of the fish and other phosphatic excreta which passes directly into the water of the ocean, and how this came to be collected together into beds of coprolite and of phosphatised wood, both important fertilisers in Europe and America, and likely to be in Western Australia, is at present a closed book.

There is plainly room for a large amount of scientific work in the story of the cycle of natural phosphorus, including investigations of the actual organisms which are capable of secreting phosphatic materials, and the form and proportions in which it is secreted, the concentration and chemical composition of the phosphorus compounds formed at all intermediate stages, and their solubility in natural waters, and finally, the composition and chemical properties of the many minerals occurring in the natural concentrations now used or still lying useless through insufficient concentration or deficient solubility.

Prof. Samoilow has devoted some time to this phosphorus question, but complains with others of the almost total absence

of precise chemical analyses of the skeletal parts of living organisms. One of the most striking results of Samoilow's development of this new science was greatly helped by the discovery of F. E. Schulze, that portions of the skeletal system of the Xenophyophora, a group of marine Rhizopods, consisted of almost pure barium sulphate in the form of minute granules. According to Samoilow the abundance of living organisms of this type off the coast of Ceylon amply explains the abundance of nodules of barite which can be dredged from the sea bottom in the locality, and points to the possibility of an abundance of such organisms in the past being the explanation of the occurrence of similar nodules of commercial importance found in certain marine beds in Europe. On the strength of this generalisation he has been able to trace numerous important occurrences of barite in Russia to a very limited geological horizon, to prove their wide extension within, but not above or below this horizon, and to predict their extension to regions not hitherto recognised as carrying concentrations of barium sulphate. This is a fact of far reaching importance in its influence on the work of the economic mineralogist.

Following on this discovery Samoilow turned his attention to one of the chief sources of commercial strontium, viz., the celestite (strontium sulphate) deposits of Turkestan. Here again the whole of the deposits appeared to be confined to sedimentary rocks of a limited horizon and the discovery by O. Bütschli that strontium sulphate was a major component of the skeletal substance of the Acantharia, a group of Radiolaria, led to the conclusion by Samoilow that these celestite deposits owed their origin to similar causes to those which produced the Russian barite deposits, viz., the extraction from sea water, and concentration of the minute proportion of strontium there existing, by the agency of living organisms. This conclusion must necessarily affect profoundly all future prospecting and exploitation of this mineral in sedimentary formations.

Samoilow has further pointed out the fact that other valuable metals, viz., copper, vanadium and manganese are essential and concentrated constituents of portions of certain living animal organisms and may have been to a much greater extent in past ages. He has discussed the extent to which this fact may influence our present theories regarding the origin and distribution of those necessary metals in the following words:—

\* "The deficiency of our knowledge with regard to the chemical composition of contemporaneous animals is very much hindering the progress of the investigation of this problem. . . . It would scarcely be reasonable to suppose that all the facts concerning this problem are restricted to those so recently and so unexpectedly dis-

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\* Minl. Mag., 1917, xviii., pp. 97-98.



covered, and that we are standing before some new and not less remarkable discovery. But even remaining within the limits of the facts already established, we must concede that a thorough mineralogical elucidation of the nature of this accumulation of strontium, copper and vanadium through the agency of vital processes should be considered seriously. And when we admit that the various organisms characterised by these mineral properties, although less numerous in the contemporaneous epoch, might have been more abundant and appear as a common and widespread group at some remote period of the earth's history, it will be clear then what importance must be attached to the detailed elucidation of all these questions for the proper understanding of the genesis of various minerals occurring in sedimentary rocks."

With this quotation from the pen of a distinguished foreign scientist I will bring my address to a close. I have endeavoured to-night to direct your attention to the moribund state of one of our greatest industries, and to the necessity for its rejuvenescence on broad grounds of national insurance. In doing this I have sketched for you one or two successful scientific investigations which have led to the utilisation of new minerals or the discovery of new sources of long known ones, and I have suggested directions in which scientific research may be expected to benefit the mineral industry and at the same time increase the security of the Commonwealth. Now more than ever is our country ready to benefit from the work of our scientists, and I feel sure that they will rise to the occasion.

EDWARD S. SIMPSON.

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